Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Assessing radiological consequences of fallout from nuclear weapon use on Swedish territory

Anders Axelsson
Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

Introduction

- Project to assess radiological consequences of nuclear explosions started in 2018
- Initial study to conclude in 2022
- Continued work is anticipated building on results of initial study
- Study conducted within the SSM units for
  - Development of Emergency Preparedness and Response
    Anders Axelsson, Anna Maria Blixt Buhr, Jan Johansson, Peder Kock, Jonas Lindgren
  - Implementation of Emergency Preparedness and Response
    Jonas Boson, Simon Karlsson
  - …and supported by Ulf Bäverstam (SSM, retired)

Objectives

Long-term capability building regarding effects of nuclear explosions

- Advice on emergency actions to mitigate consequences for the public
- Assistance to the Swedish Armed Forces with fallout calculations and advice on radiation protection for personnel

Short-term goals

- During 2021:
  - Conclude development of source terms
  - Conclude preparation of dispersion and dose modelling
  - Start production calculations
- During 2022: Publish report on radiological consequences of nuclear explosions for various scenarios
  - Improve SSM ability to contribute to exercises, emergency response planning, and development of operational capability (e.g. radiation measurements)
  - Basis for further development of knowledge and capabilities

Overall idea

- Source terms and source descriptions representative of nuclear explosions (various scenarios)
- Dispersion and dose modelling for a representative set of weather data
- Maximum distances where dose criteria of interest are exceeded for a significant fraction of weather conditions
- Broadly similar methodology was used to produce recommendations for new emergency planning zones and distances around Swedish NPPs

Some challenges compared to dispersion and dose from NPP emergency events

- Relevant scenario specification (yield, location, type of employment, *etc.*)
- Selection of nuclides to be modelled
- Particle size spectrum
- Source description: activity content and distribution

Scope

- Radiological consequences at some distance from a nuclear explosion
- No direct effects (blast, thermal, initial radiation, ground zero activation)
- No global-scale dispersion
- Only local fallout, with potential implications for emergency actions
- Time window (very roughly) 1 h < T < 1 year

Possible scenarios

- Air burst
  - Not considered at this point; focus is on local fallout with potentially major radiological consequences
- Ground surface- or near-surface burst
  - Use source description based on KDFOC3*
- Multiple, simultaneous, close and identical ground surface bursts
  - As above; use one cloud, appropriate multiples of activity content
- Water surface or near-surface burst
  - No appropriate model at present
- Pu dispersion without significant nuclear yield
  - Not the focus of this study

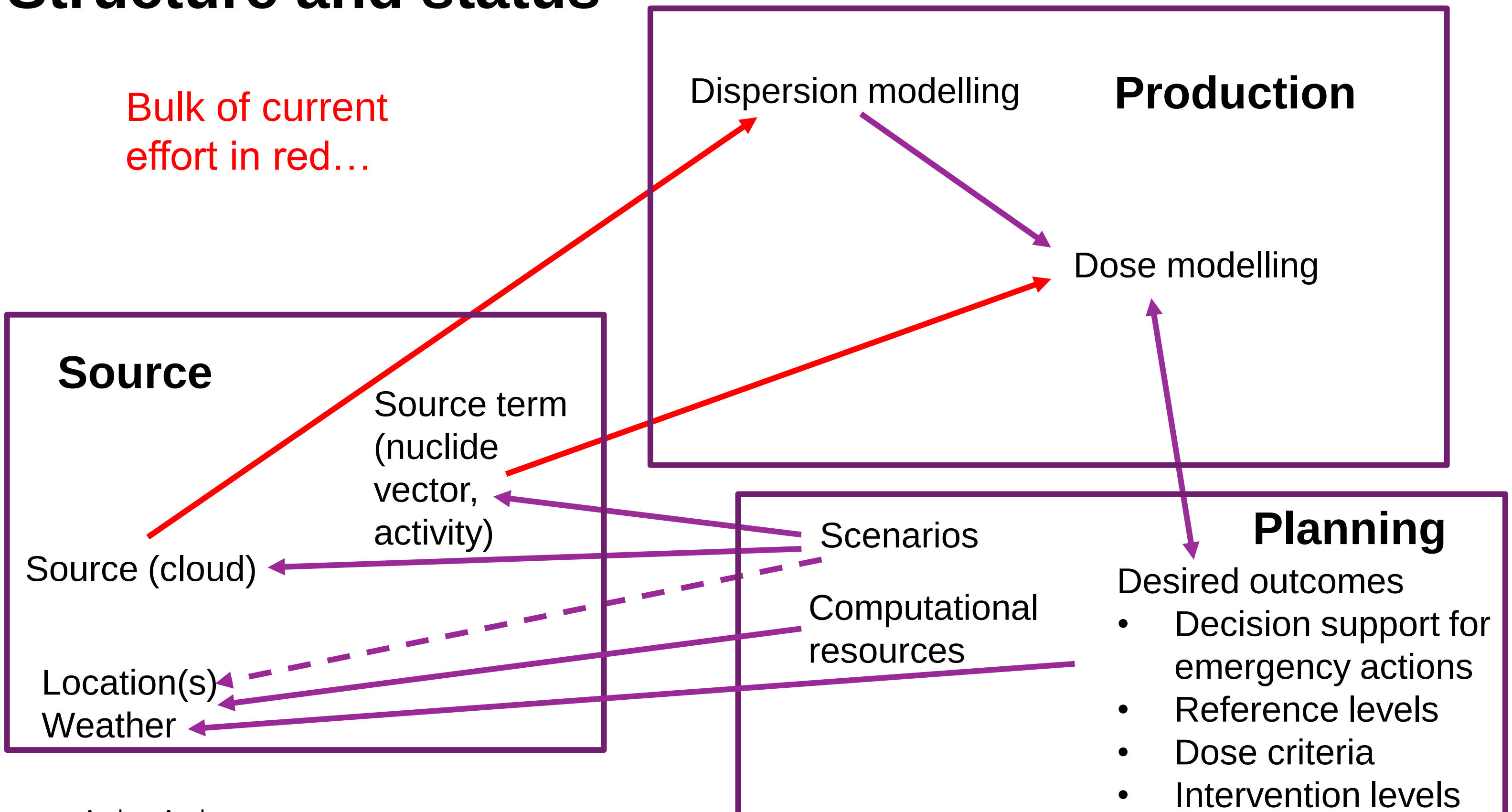
*T. Harvey *et. al.*, *KDFOC3: A Nuclear Fallout Assessment Capability*, Lawrence Livermore National Laboratory, UCRL-TM-222788 (1992)

Methodology

- Source and dispersion model MATCH-Bomb
  - Eulerian model developed by SMHI and run at NSC (National Supercomputer Centre)
  - Constructs initial ”stabilized cloud” with activity distributed by particle size fraction and altitude; model based on KDFOC3
  - Disperses stable ”H+1 activity” (fractions of initial inventory)
  - Computes nuclide inventories at later times based on decay of provided ”nuclide vector”
- ”Nuclide vector”: Same nuclide composition on every particle
  - Nuclide composition of fallout evolves over time but same evolution everywhere
  - In other words, fractionation is not modelled
  - Scenario specific
  - Incorporates the most dose-relevant fission products and activation products
- Dose modelling with ARGOS
  - ARGOS receives MATCH-Bomb nuclide-specific activities and computes doses from different exposure pathways
- Batch processing to produce desired statistical quantities

Structure and status

Bulk of current effort in red…



Anders Axelsson

Nuclide vector

- Initial candidates: fission products
  - Independent fission yield evaluated at T=10 minutes (approximate “stabilized cloud” time)
- Initial candidates: activation products
  - Relative amount: Use KDFOC3 ”rule of thumb” that adds a fraction of ”fission equivalent kilotons” of dose per kiloton of fusion yield
  - Specific nuclides: Hopefully sensible guess based on the analyses by Hicks* of (primarily) NTS fallout combined with publically available data about the tests
- Un-fissioned fission fuel is not considered
- Final nuclide selection primarily based on contribution to
  - External gamma dose from ground: >95% of TED in time windows 1 day to 1 year accounted for
  - CED from inhalation: >95% of CED at T=60 minutes accounted for

*H. G. Hicks, *Results of Calculations of External Gamma Radiation Exposure Rates from Fallout and the Related Radionuclide Compositions* (parts 2,3,4 and 8), Lawrence Livermore National Laboratory, UCRL-53152 (1981), and similar analyses by the same author

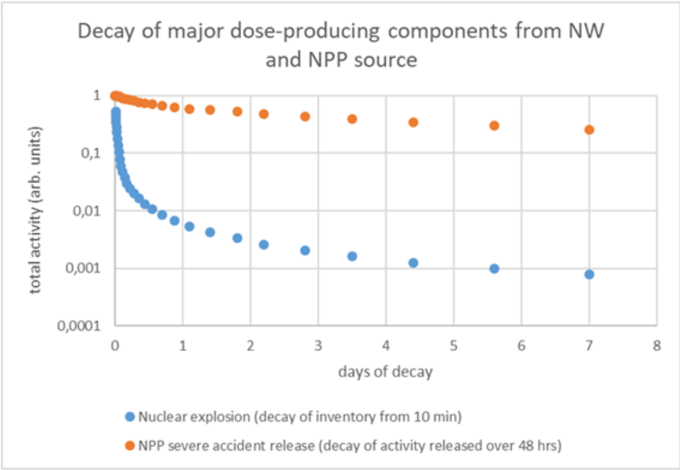
Nuclide vector (cont'd)

- All noble gases with $T_{1/2}$ > 1 minute included
- Additional nuclides included (markers): ^{137}Cs, ^{90}Sr
- Do not want to specify contributions of possible fission reactions
- Do not want to arbitrarily select one fission reaction
- ”Conservative” choice might be ^{238}U(h) (produces the highest activity), but *e.g.* ^{239}Pu(f) produces much more iodine…
- ”Max vector”: for each selected nuclide, the inventory used is the maximum among the numbers produced from three potentially contributing fission reactions – ^{235}U(f), ^{239}Pu(f) and ^{238}U(h)
- ”Max vector” over-estimates total dose by 10 – 20 % (depending on time window)

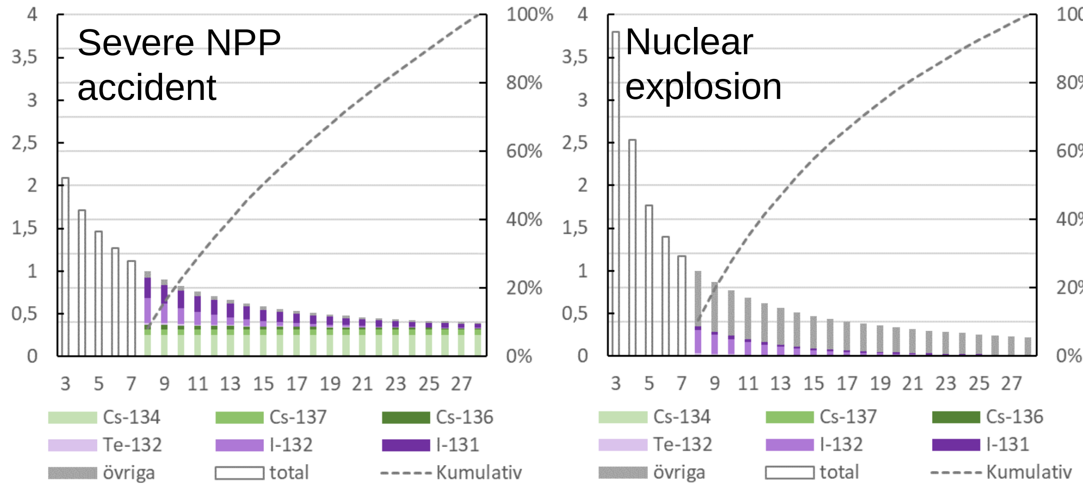
Comparing NW and severe NPP accident nuclide vectors

- More nuclides need to be considered to account for 95% of dose: 128 vs. 30
- Much higher proportion of short-lived activity

Decay of total activity



24-hour doses from ground (relative to 8th day dose)



Anders Axelsson

MATCH-Bomb and ARGOS-related work

- Some challenges compared to NPP releases
  - Larger number of nuclides need to be modelled
  - Some nuclides not previously considered
  - Source description (stabilized cloud, activity content and distribution)
- Decay data parameters
  - Nuclear data (JEFF-3.1) for new nuclides to MATCH-Bomb and ARGOS/FisPro
- Dose coefficients
  - Most nuclides are already handled by ARGOS
  - Dose data for some others are available and need to be introduced to ARGOS
  - Dose data for some are not available and need to be estimated…
- Source description harmonization
  - Ensure that pre-existing ”source generator” is consistent with current needs regarding scenario-specific nuclide vector

Expected output

- Maximum distances where selected dose criteria are exceeded for a given percentile of foreseeable weather conditions
- Exposure pathways considered:
  - Gamma dose from ground
  - External dose from cloud
  - Inhalation dose
  - Thyroid organ dose
- Doses for time windows: 1 day, 1 week, 1 month, 1 year
- Adult and one-year old infant

Expected outcomes

Insights regarding

- Reasonable reference levels and dose criteria in a state of war and in the context of nuclear weapon use
- Possible emergency actions that need to be considered given *e.g.* time available and distances
  - Evacuation: Outdoor total effective dose: (20), 100, 500, 1000 mSv
  - Sheltering: Outdoor total effective dose: (10), 100, 500 mSv
  - Iodine thyroid blocking: Thyroid organ dose: 50, 100, 500 mGy
  - Combinations of protective actions also considered
  - Sheltering with various shielding factors also considered

Improved modelling tools for scenarios including nuclear explosions

Some issues that will remain to be addressed…

- Source description appropriate for water surface or underwater burst
- Differentiated source description for varying ground/rock/environment composition
- Fractionation at source (nuclide – particle size)
- ”Fractionated dispersal” (e.g. noble gas decays to other substance during transport…)
- Further studies of activation (”how bad can it get”?)
- Possible need for further dose factors
- Improved modelling of external dose from cloud
- Variation of scenarios to improve basis for recommendations on emergency actions